HEMA – Tested in Biological Environment for Wear Resistance

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Engineers, biologists and surgeons face a special task when they design procedures, components and systems to replace tissues damaged beyond any limits, caused by disease or trauma. It has been proven that titanium and its alloys have an excellent biocompatibility, that's why many studies have been made on them, in order to enhance their biomedical applicability. In this paper, the wear behavior of HEMA was analyzed, for use as a cartilage substitute , in experimental models in vivo for testing under conditions very close to reality for two new materials, Ti12Mo and Ti25Nb25Ta alloys.

Keywords: titanium alloy, synovial fluid, HEMA

Studies on joint implants must be undertaken with caution because of the biological specificities and tribological function of the joint in vivo. The biological experiments on living tissues give results depending on the physicochemical properties of the environment in which they are performed. The tribological behaviour of the contact depends on the mechanical properties of the system and on the properties of the materials in contact. The experimental model designed and used in this work is an ex vivo reconstitution of the mechanical and physicochemical properties of the implant components. We have used the two titanium alloys to study the femoral implant component. HEMA (hydroxyethyl methacrylate) was used as an counterface because it presents mechanical and physiochemical proprieties close to the ones for the articular cartilage. Hydrogels come closest to the structure of articular cartilage, taking into account that articular cartilage contains in its structure 80% water. Hydrogels are biomaterials that consist of a crosslinked polymer chain network, obtained from hydrophilic polymers resulting in a network that can absorb large quantities of water [6].

By the significance of the terms used in tribology, the first body represented by the two components in contact is formed in vivo by the articular cartilage. Ex-vivo, the first body is replaced by the material from which the prostheses are manufactured (titanium alloys- $Ti_{12}Mo$,$Ti_{25}Nb_{25}Ta$) and by the hydroxymetylmetacrilate material which simulates the cartilage. The third body of the triplet assembly is the synovial fluid, and the musculoskeletal – ligament system plays the role of the mechanism. The tribological triplet elements are presented in figure 1.

The synovial fluid is colorless, transparent and viscous with the aspect of "albumen" [1]. The liquid lubricates the joint surfaces and facilities the sliding between them during the movement [2]. The synovial fluid volume present in normal conditions in a healthy joint is about 0.5- 4 mL, depending of the size of the joint. His composition is: protein 20 mg/mL; albumin – 7-18 mg/mL; globulin – 0.5-2.9 mg/mL; glucose – hyaluronic acide -3mg/mL; lipids (phospholipids) – 3 mg/mL [3].

The geometry of the bodies in contact was adopted as a simple one in order to obtain the same contact pressure and to compare the obtained results. The titanium alloy samples are small plane cylinders, with a spherical transparent counter face made of HEMA (8 mm radius).

The development of the $Ti_{12}Mo$ and $Ti_{25}Nb_{25}Ta$ samples was made at I.N.S.A.(Institute National des Sciences Appliqués), Rennes, France. The samples surfaces were polished by "lapping" (polish with abrasive paste of different grits) until a smaller roughness than 0.4 μm was obtained. The paste used was OPS type with *p*H of 9.8, and the grit was 0.04 μm. There were obtained samples of the same size, with a diameter of 12 mm and height of 3

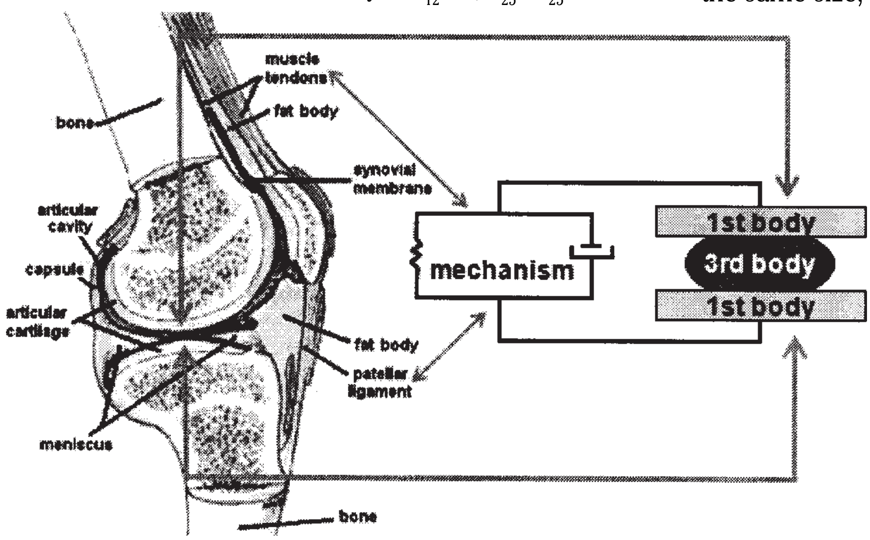

Fig. 1.The knee joint: a) anatomic view; b) the tribological triplet for the joint

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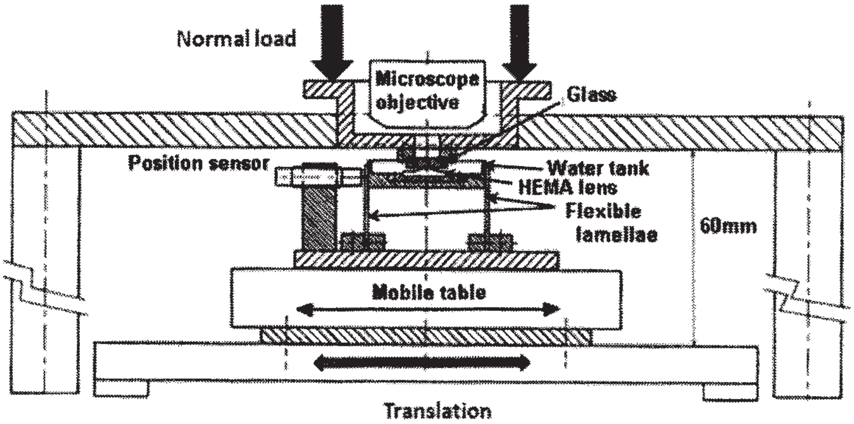


a) scheme of the device

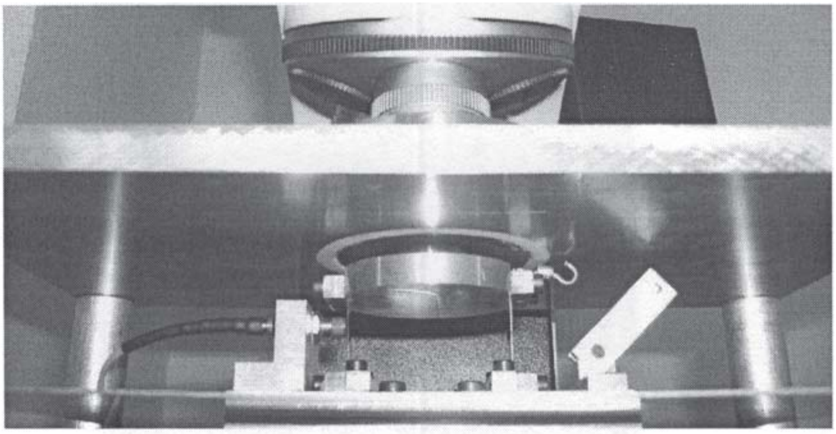

b) device

Fig. 2. Experimental device

mm).

During the friction tests carried out in this study, a simulated ex-vivo synovial fluid has been used as lubricant [4].

Experimental part

The experimental determinations have the following successive steps:

- morphological and physicochemical investigation of the surfaces before friction;
- friction tests
- morphological and physico-chemical investigation of the surfaces after the friction.

The tribological mechanism of the joint model of a knee prosthesis is simulated using an experimental device which allows a tribological investigation of the contact through friction measurements and through in situ visualization.

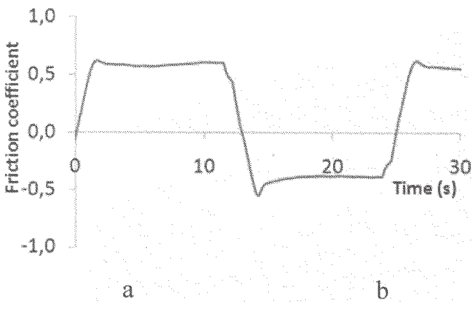
The support with the titanium sample and the flexible lamellar system is fitted on a mobile motorized table. A normal force represented by masses of circular form is applied by gravitation. The optic microscope (Leica DMLM) grants the observation of the contact through the transparent counterface. This observation is realized in situ during friction, and it can be made in white (classic), green and blue light (fluorescence). When the green or blue light are used, the acquisition parameters must be maintained constant, to be able to compare the different quantities of fluorescents lipids present in contact. The position sensor is fixed near the flexible lamellas and operates on Foucault currents, capturing the elastic strain of the lamellas during the movement. In this way, the tangential force of the whole set-up is measured [5].

Results and discussions

HEMA and Ti12Mo alloy friction test

Observing the surface and monitoring the friction coefficient in situ, it was noticed that at the beginning of the test, the synovial substitute stays in contact and forms lamellas perpendicular orientated on the friction direction. During friction, these lamellas enfold, creating rollers which are elongated and accumulate at the contact limit. The rollers and lamellas are adherent at the bodies in contact. This phenomenon imposes the change in the sense of the friction and the measurement of the adhesion stress which is about 0.2N for rollers.

The images taken by fluorescent optic microscope attest the presence of rollers of about some μm in diameter and some centimes of μm, in length on the glass surface and lamellas which tend to roll up on the HEMA.



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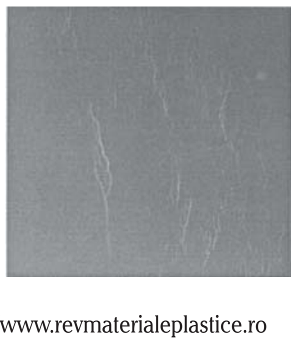
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Fig.3. a) Friction coefficient graphic (0,5) with adhesion stress (0,2N –rollers) ;b) Image of HEMA surface in fluoresent optic microscopy – blue light , at the end of friction

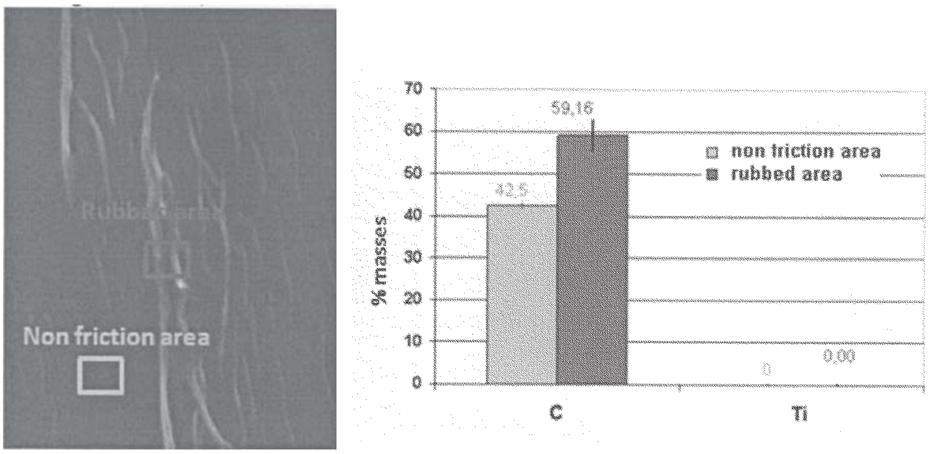

Fig. 4.Image SEM of HEMA surface – topography and elements on the HEMA surface

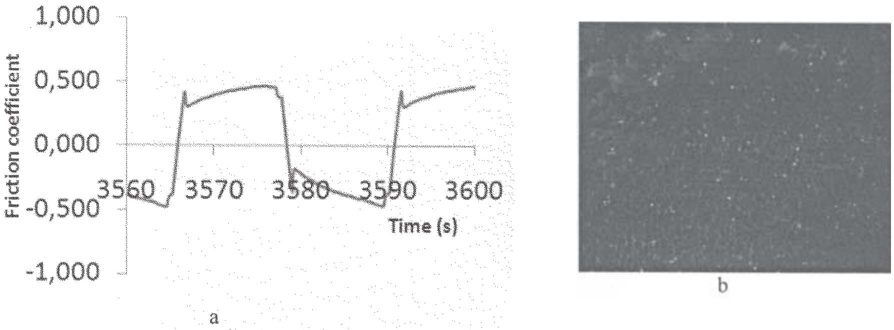

Fig. 5 (a)Friction coefficient (0,4) and (b)image in optic microsocpy- blue light(small rollers) of $Ti_{25}Nb_{25}Ta$ sample surface

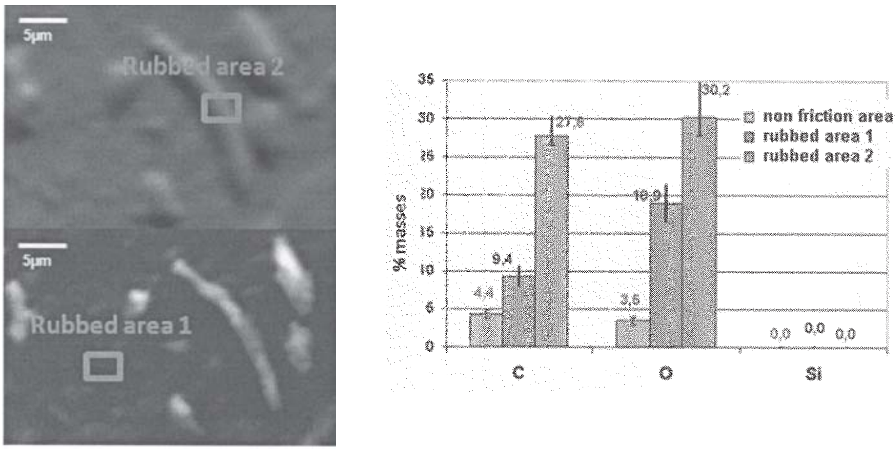

Fig. 6 a) Elements on the HEMA surface;b) image SEM of HEMA surface -topography

The analysis of the rubbed surfaces confirms that the wear of the titan samples is practically zero in the presence of the synovial substitute and HEMA counterface.

The MEB analysis showed the HEMA surface present organic rollers, which contain an important percentage of carbon, and the titan one presents organic lamellas and rollers.

HEMA and $Ti_{25}Nb_{25}Ta$ alloy friction test

It can be observed in visualization in situ that at the beginning of friction, the synovial substitute remains in contact zone, but is visible only in that zone and on the elongated friction trace.

More, in the contact zone, can be noticed small alternative arcs in the more clear and darker areas, the last representing the adhesion areas between the two bodies in contact, meanwhile the clear ones are zones where the synovial substitute have been placed well in contact. This adhesion zones are correlated with a pick of adhesion on the friction trace.

The analysis optic with microscope fluorescence attests the presence of very small rollers on the titan surface, which give the impression to be fragmented. Also it can be noticed the presence of the fluorescent molecular layers which are pressed in the contact zone and roll-up, and accumulated at the edge of the contact.

Investigating the rubbed surfaces, it can be stated that the wear of the titan sample is practically zero in the presence of the synovial substitute and counter face HEMA.

The SEM analysis show on the HEMA surface very fine elongated traces on the friction direction which can be due to a low wear of the titan, and organic rollers which are present at the edge of contact. On the titan surface very small rollers are present, but no traces of wear were detected.

Conclusions

The objective of this paper was to study the tribological behavior of HEMA rubbed against the two new titanium alloys ($Ti_{12}Mo$ and $Ti_{25}Nb_{25}Ta$) in synovial fluid simulated ex-vivo.

The design of these alloys was conducted to improve the performance of titanium in biological environments and expand its range of use, including using it as friction torque.

The presence of the HEMA counterface leads to the formation of rollers during friction, that can explain the presence of the adhesion peak on the friction curves. The wear of the HEMA surfaces is practically zero. It is observed that the wear for $Ti_{25}Nb_{25}$ Ta and $Ti_{12}Mo$ is almost the same , but the $Ti_{25}Nb_{25}Ta$ presents a greater coefficient of friction.

This could be due to:

- a different distribution of stresses inside the body in contact due to the difference in mechanical behaviour (modulus of elasticity, super strength) and a difference in terms of physical- chemistry of the surface. The TI25Nb25Ta alloy sustains a molecular film of lubricant in contact but this film doesn't attach on its surface, while in the case of $TI_{12}Mo$ alloy the lubricant molecules stick on the rubbing surfaces, which explains the presence of a boundary lubricating film;

- it is known the fact that the textured surfaces have a different rubbing behavior. The TI25Nb25Ta alloy presents more roughness and porosity. To check if this texture significantly influences the tribological behavior modeling aspects coupling fluid / structure must be considered.

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